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## ON SOME GLAUCOPHANE AND ASSOCIATED SCHISTS IN THE COAST RANGES OF CALIFORNIA.<sup>1</sup>

THE blue amphibole or glaucophane schists of the California Coast Ranges, with which are genetically associated actinolite and garnet schists, have been objects of considerable geologic interest since they were first observed in 1877. They have been cited by Mr. H. W. Turner,<sup>2</sup> Dr. H. W. Fairbanks,<sup>3</sup> and by others from many parts of the Coast Range mountains, throughout which they are abundant.

The schists occur to a large extent as rather massive isolated outcrops, and, in general, do not show their schistose structure except upon a near examination. They vary in texture from layer to layer; a hard, compact quartzose sheet being succeeded by a wrinkled, elastic, micaceous layer, which may be followed by a dense massive variety containing but little mica. These schists are for the most part entirely crystalline, and are principally characterized by the abundance of blue amphibole or glaucophane, which they contain. Whether this blue amphibole is mainly glaucophane, crossite or riebeckite the writers have not determined. There appear to be at least two varieties of the blue amphibole present in the series, one with a wide angle between the optic axes and strong double refraction, and another with a very narrow angle and weak double refraction. For the sake of convenience, however, and in accordance with the general practice, the blue amphiboles will be referred to in this paper as glaucophane.

<sup>1</sup>The writers are indebted to Dr. J. P. Smith, of Stanford University, for assistance and advice.

<sup>2</sup>"Notes on Some Igneous, Metamorphic and Sedimentary Rocks of the Coast Ranges of California," H. W. TURNER, *JOUR. GEOL.*, Vol. VI, p. 488 *et seq.*; "The Geology of Mount Diablo, California," H. W. TURNER, *Bull. Geol. Soc. Am.*, Vol. II, p. 385.

<sup>3</sup>"The pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges," H. W. FAIRBANKS, *Am. Geol.*, Vol. IX, p. 160; "Notes on a Farther Study of the pre-Cretaceous Rocks of the California Coast Ranges," H. W. FAIRBANKS, *Am. Geol.*, Vol. XI, pp. 70-73.

Of less importance though widely distributed and intimately associated with the glaucophane is the light green actinolite schist which occurs with the glaucophane schist in irregular layers and masses. Both of these schists have garnets abundantly developed in them.

Dikes of serpentinized peridotite and also of diabase are commonly found in apparent association with the schists. It was on such an association that Dr. F. L. Ransome<sup>1</sup> based his hypothesis that the Angel Island glaucophane schist is the result of the contact action of fourchite and peridotite intrusions in the Golden Gate or Franciscan sandstones. Ransome's conclusions are questioned, however, by Turner,<sup>2</sup> who says: "It is yet to be demonstrated that these schists are the result of contact metamorphism."

In a short note in his paper on metamorphism, Professor C. R. Van Hise<sup>3</sup> refers to the glaucophane schists of the northern end of Calaveras Valley, in Alameda county, as resulting from dynamic agencies, and says they are formed from igneous rocks by crushing.

The writers have examined several localities where the schists occur, and where their relationship with accompanying rocks is clear. The principal ones are four in number: one about two miles southwest of Healdsburg, Sonoma county, one at Camp Meeker, Sonoma county, one mentioned by Van Hise in the northern end of Calaveras Valley, Alameda county, and one on Tiburon Peninsula, Marin county, in which the lawsonite described by Ransome<sup>4</sup> occurs. Besides these, many smaller exposures have been studied between Healdsburg and San Luis Obispo county, and especially in the region around the bay of San Francisco.

<sup>1</sup>"The Geology of Angel Island," F. LESLIE RANSOME, *Bull. Dept. of Geol. Univ. of Calif.*, Vol. I, No. 7, p. 211.

<sup>2</sup>*Loc. cit.*, p. 491.

<sup>3</sup>"Metamorphism of Rocks and Rock Flowage," C. R. VAN HISE, *Bull. Geol. Soc. Am.*, Vol. IX, p. 313.

<sup>4</sup>"On Lawsonite, a New Rock-Forming Mineral from the Tiburon Peninsula, Marin county, California," F. LESLIE RANSOME, *Bull. Dept. Geol., Univ. of Calif.*, Vol. I, No. 10, p. 311.

*Healdsburg.*—At Healdsburg the schist area is nearly a mile wide and more than four miles long. The thickness of the schist is several hundred feet, though no exact measurements have been made. From about half a mile south of the Junction Schoolhouse, which is two miles southwest of Healdsburg, the schists form a range of hills which extend in a general north-westerly direction for several miles. In the southern end of this area the schists are in contact with serpentine, and overlie a boss or laccolite of it. The contact is clear and unmistakable, as the rocks stand up above the soil, and hand specimens may be secured which show the parting between the schist and serpentine in a single fragment. In the serpentine boss is an irregular mass of gabbro—possibly a result of magmatic differentiation. In addition there are at least three serpentinized dikes in the schist area northwest of the Junction Schoolhouse, and also a small outcrop of diabase.

With the exception of one place where it grades into shale, the schist is entirely crystalline, and is composed mainly of glaucophane, actinolite, garnet, epidote, and various light-colored micas. Some layers are very quartzose and are composed mainly of quartz, glaucophane, garnet, epidote and a little white mica. The schists vary much in texture and mineral composition, but are easily recognized, as there are no other rocks like them in this locality.

South of the Junction Schoolhouse a fragment of actinolite schist was found in the serpentine, and its plane of schistosity makes a large angle with the planes of neighboring masses of schist. It is clearly an inclusion and points definitely to the serpentine being intrusive in and younger than the schist. Ransome, in his paper on the geology of Angel Island, mentions similar inclusions in the serpentine there.<sup>1</sup>

About a quarter of a mile southwest of the Junction Schoolhouse the schists appear to be overlain unconformably by Golden Gate or Franciscan<sup>2</sup> sandstones. This relation is not entirely

<sup>1</sup>*Loc. cit.*, p. 225.

<sup>2</sup>As the Franciscan or Golden Gate rocks are unfossiliferous, their identification away from the type localities is based on lithologic features and field relations, and is consequently uncertain.

certain, however, as the rocks may have been faulted into their present position. About two miles north of the Junction Schoolhouse, on the eastern flanks of the hills, are jaspers intruded by a serpentinitized dike which has apparently had but little metamorphic effect.

In a hillside cut on the Healdsburg road about half a mile east of the Schoolhouse, there is an excellent gradation from slightly altered shale to entirely crystalline glaucophane and actinolite schist. Specimens can be collected showing every degree of alteration. Thin sections of the least altered shale show incipient development of glaucophane in crystalline tufts and radiate aggregates.

*Camp Meeker.*—At Camp Meeker, Sonoma county, about twenty-five miles southwest of Healdsburg, glaucophane and actinolite schists are developed over an area which appears to be at least a mile wide and several miles long, though the limits were not determined.

Intrusive in the schist are small dikes of a pyroxene rock which are themselves somewhat schistose, and have glaucophane, actinolite, chlorite and mica developed in them. On each side of these dikes the schist is of the normal glaucophane type and contains glaucophane, actinolite, garnets and white mica. North-east of the schist area is a mass of serpentine, but at no point examined was the relation between the two rocks clearly shown.

About half a mile north of Camp Meeker there is a gradation from schist to shale in a distance of about three hundred feet. *The shale is hard and wrinkled*, and contains some secondary mica, but no glaucophane or actinolite.

*Tiburon.*—The glaucophane schist area on the Tiburon peninsula is about two hundred yards wide, and extends more or less continuously from Tiburon to north of Reed's station. Northeast of the schist is serpentine which caps the hills; and southwest are sandstones and shales. Near Reed's station, however, there is a small area of the sandstone and shales, which, on the surface, lies between the schist and the serpentine, and is in contact with the serpentine. At the immediate contact the shale is somewhat hardened but is unaltered at a distance of three feet.

*Calaveras Valley.*—In the northern end of Calaveras Valley, northwest of Mount Hamilton, in Alameda county, there is an area of glaucophane and related schists, which can best be studied in the canyon of the Arroyo Hondo. There are two series of glaucophane-bearing rocks in this locality; one a massive crystalline rock, one facies of which is an eclogite containing, principally, garnet, omphacite, glaucophane and actinolite. The other facies is a medium grained, light colored, banded rock composed principally of quartz, glaucophane, garnet, and white mica. The garnets are in the form of very small crystals which are included in the quartz and glaucophane.

The other series of glaucophane-bearing rocks overlies this massive one unconformably, and consists of thin bedded sandy shales having a vertical dip and a northwesterly strike. They are much contorted, however, and are hard and schistose in places. These beds are unfossiliferous, but are overlain unconformably by Lower Miocene sediments. They resemble to a large extent the sandy shales of the Golden Gate or Franciscan series, and it seems probable that they belong with those rocks. Glaucophane is developed in them irregularly, one bed being blue with it, while the adjoining one on either side may contain but little glaucophane. White mica is developed in these beds in many places, and narrow quartz veins are common.

In the southern end of the canyon are masses of serpentine, but the contacts between them and the adjoining rocks are not exposed.

In contact with the massive banded rocks is a hard, heavy, compact, greenish rock, with bands and stripes of glaucophane plentifully distributed through it. It may be an altered serpentine, but thin sections of it show no definite minerals. It is apparently a dike intrusive in the banded rock, but it has probably been altered since, and may have been subjected to the same agencies that produced the banded rock.

*Conclusions.*—No one explanation seems to satisfactorily account for the many different aspects and occurrences of the glaucophane and related schists. That there has been some development of glaucophane at the contact of basic igneous

masses seems certain. It seems improbable, however, that the main portion of the normal glaucophane and actinolite schists is a result of contact action. That the schists have not resulted from contact action by peridotite masses seems probable, for at some points the same masses have certainly produced but slight alteration in adjoining sandstones and shales, and the thickness and character of the schists is such that they could only have been produced by metamorphosing agents acting on a large scale. It seems difficult to believe, also, that the schists could be formed by serpentine dikes which are smaller than the schist masses themselves. Besides, the inclusions of schist in the Healdsburg and Angel Island serpentines render it almost certain that the schists are the older of the two rocks. In addition, the evidence points to the massive glaucophane rocks and normal schists being older than the Golden Gate or Franciscan series of rocks, for the schists are unconformably beneath what appears to be the Golden Gate or Franciscan rocks in the Calaveras Valley, and they probably have similar relations at Healdsburg. Finally, serpentinized dikes are frequently found intrusive in Golden Gate or Franciscan rocks, while at Mount Diablo,<sup>1</sup> near Gilroy,<sup>2</sup> and in San Luis Obispo county,<sup>3</sup> there are serpentine dikes intrusive in the Knoxville beds. This would of course make the dikes younger than the schists, if the schists are older than the Golden Gate or Franciscan series.

In some cases the schists have been formed directly out of sedimentary rocks, and probably in some cases out of tuffs or other igneous material. The writers have observed cases in which basic igneous dikes have had glaucophane and other secondary minerals developed in them, and have become more or less schistose.

It can hardly be doubted that glaucophane schists have been developed in rocks of different ages, and older than the Knoxville. It seems probable, also, that there is a series of

<sup>1</sup>*Loc. cit.*, p. 390.

<sup>2</sup>Communicated by Dr. J. P. Smith, Stanford University.

<sup>3</sup>"The Stratigraphy of the California Coast Ranges," H. W. FAIRBANKS, *JOUR. GEOL.*, Vol III, p. 428.

glaucophane schists older than the Golden Gate or Franciscan, and the possibility suggests itself that these may be but isolated outcrops of extensive masses which underlie the Coast Ranges.

The only hypothesis that seems to satisfactorily explain the occurrences of these rocks is that they are the result of dynamic agencies, and may or may not be the products of widespread regional metamorphism.

EDWARD HOIT NUTTER,  
WILLIAM BURTON BARBER.

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